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Written Testimony

of

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for the
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Subcommittee on Fisheries Conservation, Wildlife and Oceans
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"Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003"
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The U.S. Harmful Algal Bloom Problem

The U.S. has been experiencing a dramatic increase in harmful algal blooms (HABs) over the past 30 years. The increase has resulted in dramatic increases in fish, bird, and mammal mortalities, severe economic hardship for coastal economies dependent on seafood or shellfish contaminated by the toxins of several species, and increasing human health risks from direct or indirect exposures. Further, implementation of time-consuming and resource-requiring monitoring programs have seriously strained local government fiscal resources.

The National HAB Plan

US researchers and agency officials realized the serious consequences of HABs on the US coast over twenty years ago, developing a National HAB Plan that was published in 1993 (under revision, 2004). The Plan outlined the impacts put also recommended a national approach to first understanding the HA events through the organisms responsible, linking the organism's growth and toxin production to the surrounding physical and chemical environment, and following up with specific recommendations on distributing information for ultimate response to the recurrent events. From this Plan, a separate plan was developed to determine the factors responsible for HAB formation based on the ecology and oceanography of the harmful algal blooms or ECOHAB (1995) which now serves as the basis for the multi-agency research program of the same name. Additional reporting was undertaken for other aspects of the National Plan, resulting in a separate summary on the Prevention, Control, and Mitigation of Harmful Algal Blooms (1997) which now serves to partially guide the newer applications effort, Monitoring and Event Response for Harmful Algal Blooms (MERHAB) in NOAA's NOS Coastal Ocean Program. These documents and resulting research programs have resulted in tremendous increases in basic and applied research on U.S. HABs since 1997, fulfilling some of the objectives of the original Harmful Algal Bloom and Hypoxia Research and Control Act of 1998.

Recent Impacts of US HABs

HABs in the US have caused substantial damage to living resources, coastal economies, and human health throughout every coastal state. Some of the HA species produce toxins, such as paralytic shellfish poisons, neurotoxic shellfish poison, amnesiac shellfish poisons, diarrhetic shellfish poisons, and several other intoxications. Still other HA species accumulate to such high densities that they cause substantial oxygen demand and hypoxia or anoxia in small areas, leading to fish kills as well as beach closures due to the accumulation of dead fishes on the shore.

Economic impacts are substantial. A recent report estimates that average annual economic losses from blooms approximates $49 million (Anderson et al. 2000). However, individual bloom events can have single individual impacts approaching this mean. For example, $43 million was lost to fish and fish-related industries in the Chesapeake Bay region as a consequence of the *Pfiesteria piscicida* fish kills of 1997 in MD. In NC, a transported *Karenia breve* (red tide) population resulted in an estimated $25 million loss for the state's fish and shellfish industry. Anecdotal estimates of losses reached $120,000,000 for a single, but several month long, western Florida red tide.

Indirect costs associated with these blooms are also substantial. For example, states set up and maintain water monitoring and toxin assay programs, not a trivial resource commitment. Medical responses to HAs are largely vastly underestimated as most symptomologies of HA are assigned to general malaise of other common sicknesses, and therapies are those for general flus. Lost worker time for these exposures are unknown but not trivial.

Reasons for Blooms

There are two principal reasons for blooms of harmful algae. One, some bloom species are 'natural' phenomena, a result of growth at sea and subsequent transport to coastal areas of the world including the US coastline. These generally form independent of human activity and associated nutrient loads. Examples for the U.S. include *Alexandrium* in the northeast, west coast, and Alaska. These dinoflagellate populations produce saxitoxins and their derivatives, resulting in paralytic shellfish poisonings (PSP) from the ingestion of shellfish containing *Alexandrium* filtered from the surrounding waters by the bivalves. Mortality can occur from consumption of too much mass and ethnic populations are particularly susceptible due to language barriers and cultural differences. Although water discoloration from dense accumulations of *Alexandrium* are rare, even the relatively dilute abundances in these areas can pose serious threats when transported from offshore areas inshore.

Another bloom species transported from offshore areas inshore, again formed with little human-derived nutrient, is the Gulf of Mexico red tide organism, *Karenia brevis*. This cell produces brevetoxins leading to neurological disorders and fish, porpoise, and manatee mortalities from Florida through Texas. The seed populations are transported from nutrient-poor waters offshore to inshore more nutrient rich areas to accumulate and pose serious problems not only for the taxa noted above but for respiratory-impaired coastal populations. These blooms have been reported since late in the 16th century during the conquistador explorations in Florida and have been reported in 23 of 24 of the past years along Florida's west coast.

A final example of species developing as a result of offshore conditions and transported inshore to impact coastal systems are the *Pseudo-nitzschia* species of our West coast. Some of these species produce domoic acid, responsible for amnesiac shellfish poisonings (ASP), i.e., permanent short-term memory loss in humans (even occasional deaths) as well as high mortalities for birds, sea lions, and other coastal mammal populations of California. Along the west coast, two natural processes occur to bring these toxic populations onshore. Off California and Oregon, regional winds can induce upwelling leading to intrusion of nutrient-rich deeper waters into shallow, lighted depths occasionally leading to blooms of the toxic diatom (e.g., Scholin et al. 2000). Another mechanism is also in place, as well. Northwest of Washington, *Pseudo-nitzschia* species accumulate in a circulating eddy which, again under regional meteorological control, can be driven onshore and trapped to induce coastal intoxications. In both cases, the blooms are from these natural events, linking regional meteorology, physical oceanography, and abundant nutrients from depth in proliferation of the harmful taxa.

The other process leading to U.S. HABs is coastal eutrophication (Anderson et al. 2002). Since most of our coastal embayments receive substantial nutrient input as a result of human activity

within surrounding watersheds, the combination of high nutrient loads and long residence times of estuarine systems can foster growth of several HA species. The taxa in this group include potentially fish-killing *Pfiesteria* species as well as *Karlodinium micrum*, potential brevetoxin-producing raphidophyte populations like *Chattonella* (Delaware), oyster-killing *Prorocentrum minimum* populations, via groundwater the brown tide organism *Aureococcus aophagefferens*, and toxin-producing blue-green algae (also known as cyanobacteria).

There is substantial evidence (Burkholder et al. 1997) that *Pfiesteria* species respond to elevated nutrient loads, either directly through uptake of the essential macronutrients nitrogen or phosphorus or indirectly through ingestion of other phytoplankton that these nutrients support. Increasing dissolved inorganic nitrogen loads in the Mississippi River also appears to support a shift in coastal phytoplankton assemblages, to increasing numbers of potentially toxic *Pseudo-nitzschia* species (Dortch et al. 2004). Elevated urea levels, likely from increased use of urea-based fertilizers as well as uric acid in poultry manures, may be selecting for several dinoflagellate populations in the Chesapeake as well as the brown tide organism *Aureococcus anophagefferens* in MD's coastal Bays (Glibert and Terlizzi 1999; Glibert et al. 2001). Finally, cyanobacteria are common members of eutrophic, quiescent fresh and low salinity waters and pose serious problems for fresh water drinking supplies as several bloom species produce hepato- and neurotoxins.

The increasing frequencies of these bloom-forming events in our coastal systems encourages vigorous evaluation of processes to reduce nutrient loads to our immediate waterways. If nutrient loads are not reduced, algal growth and bloom proliferation are not unexpected, as these events are analogous to lawn and crop growth that accompanies fertilization with the same nutrients that are entering our aquatic systems.

Progress in Research

There has been substantial research progress since the formation of the interagency ECOHAB program in 1996. This program has provided funding from NOAA, NSF, EPA, and occasionally ONR and NASA, to conduct oceanographic, physiological, and ecological research on harmful algae in U.S. waters. As a competitive, peer-review driven program, ECOHAB has supported regional studies in the Gulf of Maine, Gulf of Mexico, the Pacific NW, Long Island, the mid-Atlantic states, and coastal California to elucidate bloom organism responses to local and regional conditions in hopes of determining controlling factors for the recurrent HAB events of these areas. Using laboratory- and ship-based studies, there is now substantial information on unique combinations of environmental cues and HA species responses leading to blooms in these disparate environments. Basic physiological characters of the HA species, information on the HA's neighbors and competitors, and physical and chemical conditions of the waters supporting the algae have been defined sufficiently in most cases to develop at least conceptual models of bloom formation and impact, and in some cases mathematical models of the events. The models, in turn, form the basis for forecasts being developed in the regions, with the most advanced successes found in the Gulf of Maine for *Alexandrium* and Gulf of Mexico for *Karenia*. The latter region has a user-friendly landfall and transport forecast in place (Stumpf et al. 2003), developed through use of remotely sensed chlorophyll in surface waters; the output is broadcast across the Gulf states from NOAA's Center for Coastal Monitoring and Assessment to assist in

mitigative responses in each locale, enabling most effective use of limited state resources to the HA impacts.

These studies have also developed an extensive arrays of species-specific molecular probes, permitting detection of individual HA cells in field assemblages of these rare HA populations and thousands of other non-toxic species. These probes now provide near real-time laboratory detection capabilities for most of the problem species in the U.S. The next step is in water detection where the techniques can be deployed on platforms (e.g., buoys, moorings) and autonomous underwater vehicles in the ocean, estuary, and lakes to robotically detect the problem species. Such a prototype is in place now, through Dr. Chris Scholin at Monterey Bay Aquarium Research Institute in California. His Environmental Sample Processor (ESP) houses sample collection, detection, and archiving capabilities with analyses telemetered to shore in real time. Individual species are detected with species-specific probes and in the very near future, toxin production will also be assayed on the same platform.

Toxin and toxicity assays are also in hand, with laboratory detection routine. Moving the new techniques to the sample platforms will occur rapidly as miniaturization procedures (micro- and nanofluidics) become adapted to mooring constraints (largely size). However, there are mass spectrometers (permit detection of organic compounds like toxins) now deployable in the field (e.g., University of South Florida's Center of Ocean Technology).

Optical properties of the water and suspended materials like the harmful algae also provide specific detection capacities. Dr. Gary Kirkpatrick at Florida's Mote Marine Laboratory and his colleagues have developed a long-path length spectrophotomer to identify accessory pigments associated with the red tides of the Gulf of Mexico. Called the Breve-buster for its ability to discern *Karenia brevis* in the water column, Kirkpatrick and his colleagues have mounted it on an underwater autonomous vehicle and mapped distributions of the dinoflagellate off Florida's west coast. Other optical techniques, using light absorbtion and particle backscattering now permit detection of groups of harmful algae that may be present as well as cell size. From the history of species common to an area, these two measures can narrow the species possibilities for a particular area. Finally, there are imaging techniques that permit image collection and storage of suspended particles in the water including the HA species that when downloaded, can provide direct documentation of actual species present. These flow cytometer applications promise much for routine monitoring in many low turbidity environments.

The Future for HABs in the U.S.

Progress has been extremely rapid over the past five years, largely through funding derived from the ECOHAB research program as well as its sister effort, Monitoring and Event Response for Harmful Algal Blooms (MERHAB). The latter program, run through NOAA's Coastal Ocean Program, transfers research technologies and tools to coastal management communities to assure that cutting edge research products are rapidly applied to coastal HAB problems of concern. We must continue a number of critical activities however:

1) Continue ECOHAB and MERHAB support for research and research applications. It is only through the collection of basic algal physiology, ecology, and system oceanography that we can

attempt to discern the interaction of factors that lead to the success of a given HA species in an area. From these data, predictive models can be developed to aid in forecasting future HA events and impacts. These projects must be integrated nationally as has been done very effectively through NOAA's Coastal Ocean Program and this oversight using peer review competitions selects the highest quality science without bias.

2) Expand in water technology detection capabilities. With the increasingly sensitive detection capabilities for cells, toxins, and toxicities in the on-going research efforts, it is important to deploy these technologies in the 'real-world' to permit autonomous detection of these critical measures. These early warning possibilities will then provide for more rapid responses, including mobilizing field teams, narrowing sampling locations, and setting up mitigation procedures. As ocean observing systems materialize, these technologies should be mounted in conjunction with other routine measurements of temperature, salinity, nutrients, dissolved oxygen, and currents to not only provide the real-time measures but the factors that are likely controlling the HAB's distribution. This information, in turn, sets up forecasting and modeling to permit larger system projections than would be gained from the single mooring or measurement.

3) Expand optical and remote sensing detection. Optical properties of the water and HA cells are becoming more easily recognizable with the rapidly advancing techniques for use in the water and above it proving highly specific to these recurrent events. Ocean color detection from satellites should be continued and planned in future budgeting activities.

4) Prevention, Control, and Mitigation of HABs is an important and difficult task for the US. Some natural blooms cannot be prevented as they are transported to impact a region; mitigative procedures, such as beach barriers, can be set up but prevention is generally not possible. Controlling some blooms, using physical, biological, or chemical deterrents is possible for some blooms, but on a limited basis. Funding for expanding our capabilities is encouraged. It is important to recognize that nutrient loading is extremely important is limiting algal production, including the HA species, in U.S. waters, from fresh water lakes to the coastal ocean. Nutrient management in our water and airsheds must remain a high priority if we are to expect reduced HABs in inshore and coastal waters of our nation. Not only will HABs be limited from better control of nutrient loads, but the other major emphasis of the legislation, Hypoxia, will also be reduced providing more habitat for fish and shellfish production in our heavily fished coastal oceans.

The U.S. research and management communities must work together more closely to clearly define likely algal responses to be expected from managing our coastal watersheds. Additionally, researchers must more actively identify needs of these managers in responding to HAB impacts, and redirect some of our research to these needs. Researchers and agency staffs have been supportive of each other's goals; implementing technology transfers from these two groups for coastal managers remains a developing commitment.

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Education

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1973   M.S., Marine Science; University of South Carolina, Columbia, South Carolina.
1971   B.A., Biology; Clark University, Worcester, Massachusetts.

Professional Experience

2002-   Research Associate, Smithsonian Environmental Research Center, Edgewater, MD.
1998-   Director, Chesapeake Research Consortium, Inc., STAC Executive Officer, and Visiting Professor, UMCES-Horn Point Laboratory.
1998-2001   Special Membership, University of MD Graduate Faculty, 10/21/99-10/21/01.
1997-2001   NOAA-COP, ECOHAB Coordinator, and Oceanographer. Oversee, manage, and coordinate Federal interagency (NOAA, NSF, EPA, ONR, NASA) research program on the ecology and oceanography of harmful algal blooms.
1978-1998   Curator, Associate Curator, Assistant Curator, The Academy of Natural Sciences. Basic and applied research programs in plankton ecology of aquatic systems.
1986-88   Adjunct Associate Professor, Chesapeake Biological Laboratory, University of Maryland, Solomons, MD.
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1979-80   Course design and teaching, Marine Ecology, Temple University, Philadelphia, PA.
1975-76   Instructor, St. Mary's University, Halifax, Nova Scotia. Developed, synthesized and taught laboratory course in Marine Chemistry.

Affiliations: American Society of Limnology and Oceanography, Atlantic Estuarine Research Society, Estuarine Research Federation (Assoc. Editor, 1998-), International Society for the Study of Harmful Algae, Aquatic Microbial Ecology review editor (2003-)

Student Advisory & Teaching Activities: Committee member for Todd R. Miller, Center of Marine Biotechnology, University of MD, Ph.D. candidate, 2000-. Also for Anthony Dvarkas, MEES Student, 2004-. Similar role for Master's candidates, Honor & RUE Students from regional universities. Lecturer, MEES, Spring, 2000 & 2002, University of MD, College Park. "Algal Blooms: Causes, consequences, and conjecture."

Miscellaneous Professional Activities: Former ANS Representative to CBP's Monitoring Subcommittee; Member, MD's Harmful Algae Technical Advisory Committee and Harmful

Algal Force 1997- ; Associate Editor, Estuaries, 1998-; Review Editor, Aquatic Microbial Ecology, 2003-; US Congressional Briefing, HABs and Event Response, 2000; Ecosystem Modeling and Trophy Advisory Panel Chair, Fisheries Steering Committee, 2001-; editor, EU-US HAB Research Initiative, 2003; Steering Committee member for US National HAB Plan revision, 2003-; Steering Committee member, Second US National HAB Meeting, 2003; Steering Committee member HABSOS-GCOOS workshop, 2003-.

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